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Sato et al.

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(54) **POWER SUPPLY CONTROLLER AND ENERGY HARVESTING APPARATUS**

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H01L 31/053	(2014.01)
H02J 50/05	(2016.01)
H02J 7/34	(2006.01)
H02N 11/00	(2006.01)

(52) **U.S. Cl.**

CPC ***G06F 1/26*** (2013.01); ***H01L 31/053*** (2014.12); ***H02J 7/345*** (2013.01); ***H02J 50/05*** (2016.02); ***H02N 11/002*** (2013.01)

(58) **Field of Classification Search**

CPC H02J 7/025

USPC 320/101, 108

See application file for complete search history.

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(57) **ABSTRACT**

A power supply controller controlling a connection between a power source and a capacitor coupled between a first node and a second node and a load circuit operating with electric charge of the capacitor, includes a first controller configured to output a first control signal in accordance with an electric potential difference between the first node and the second node, a first switch configured to couple or uncouple the capacitor to or from the load circuit in response to the first control signal, a first resistor coupled between the first node and the first controller, a second resistor coupled between a node being located between the first resistor and the first controller and a third node for outputting the first control signal, and a second switch coupled in parallel to the first resistor and putting into on or off state in response to the first control signal.

7 Claims, 8 Drawing Sheets

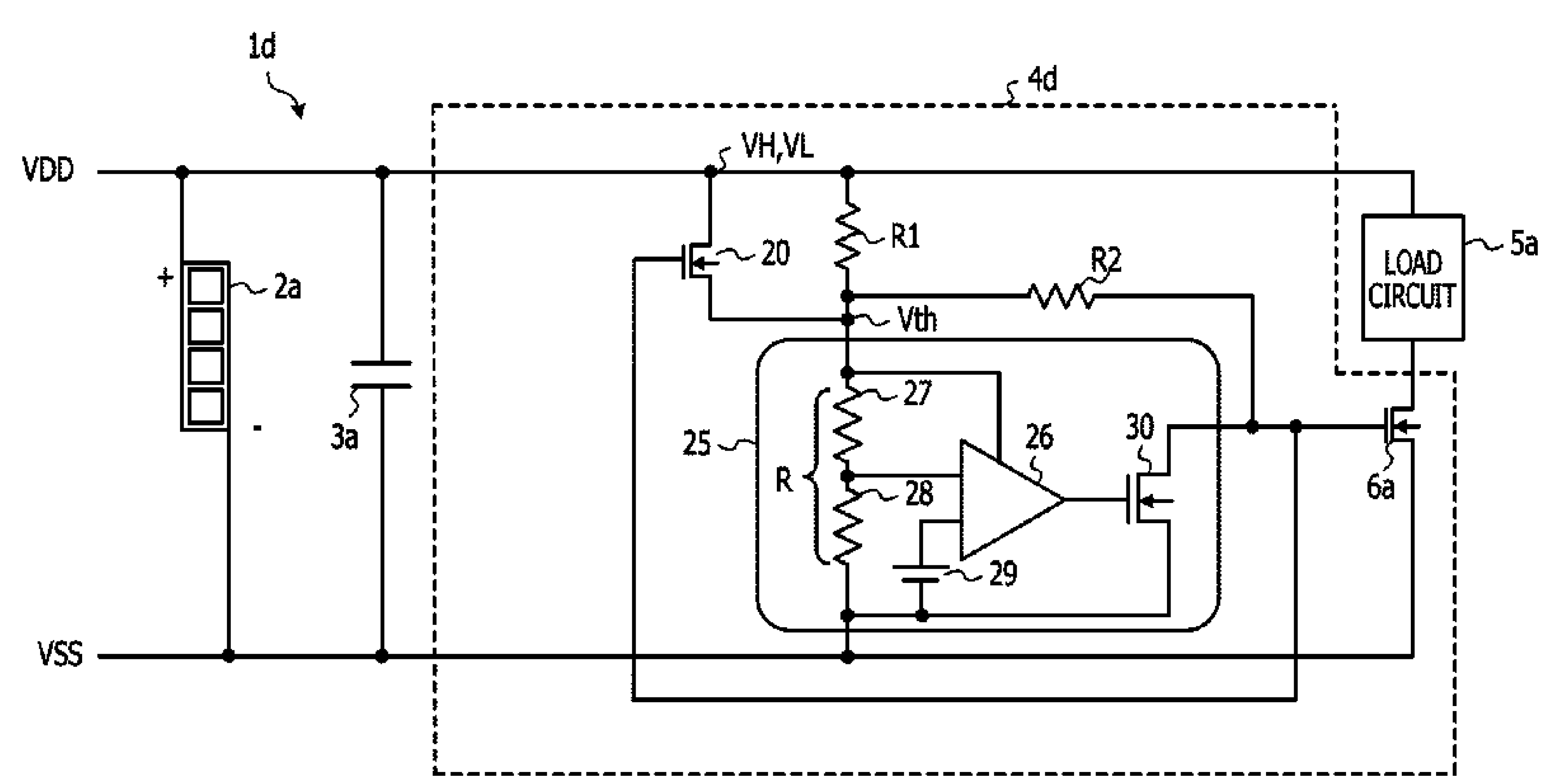


FIG. 1

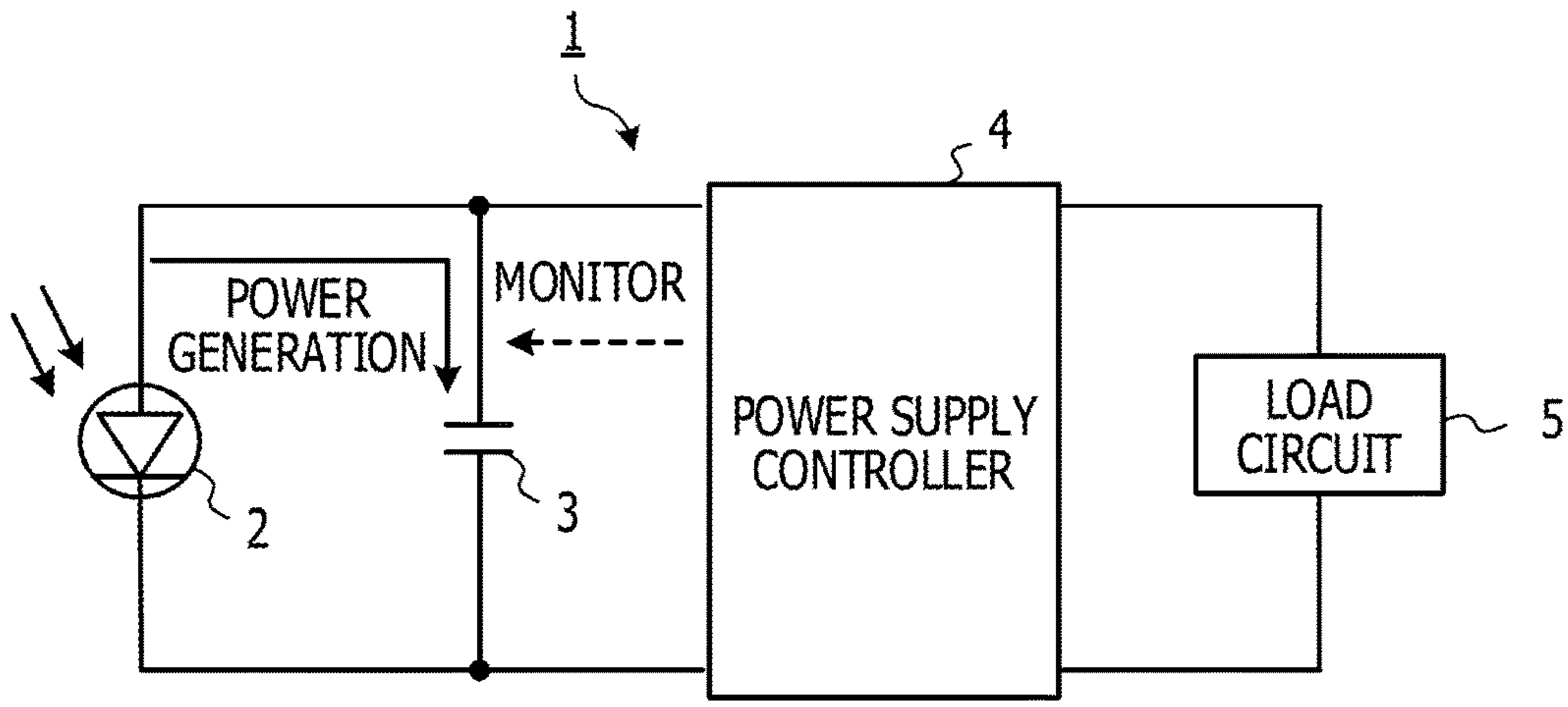

1
4
POWER GENERATION
MONITOR
POWER SUPPLY CONTROLLER
LOAD CIRCUIT
5
2
3

FIG. 2

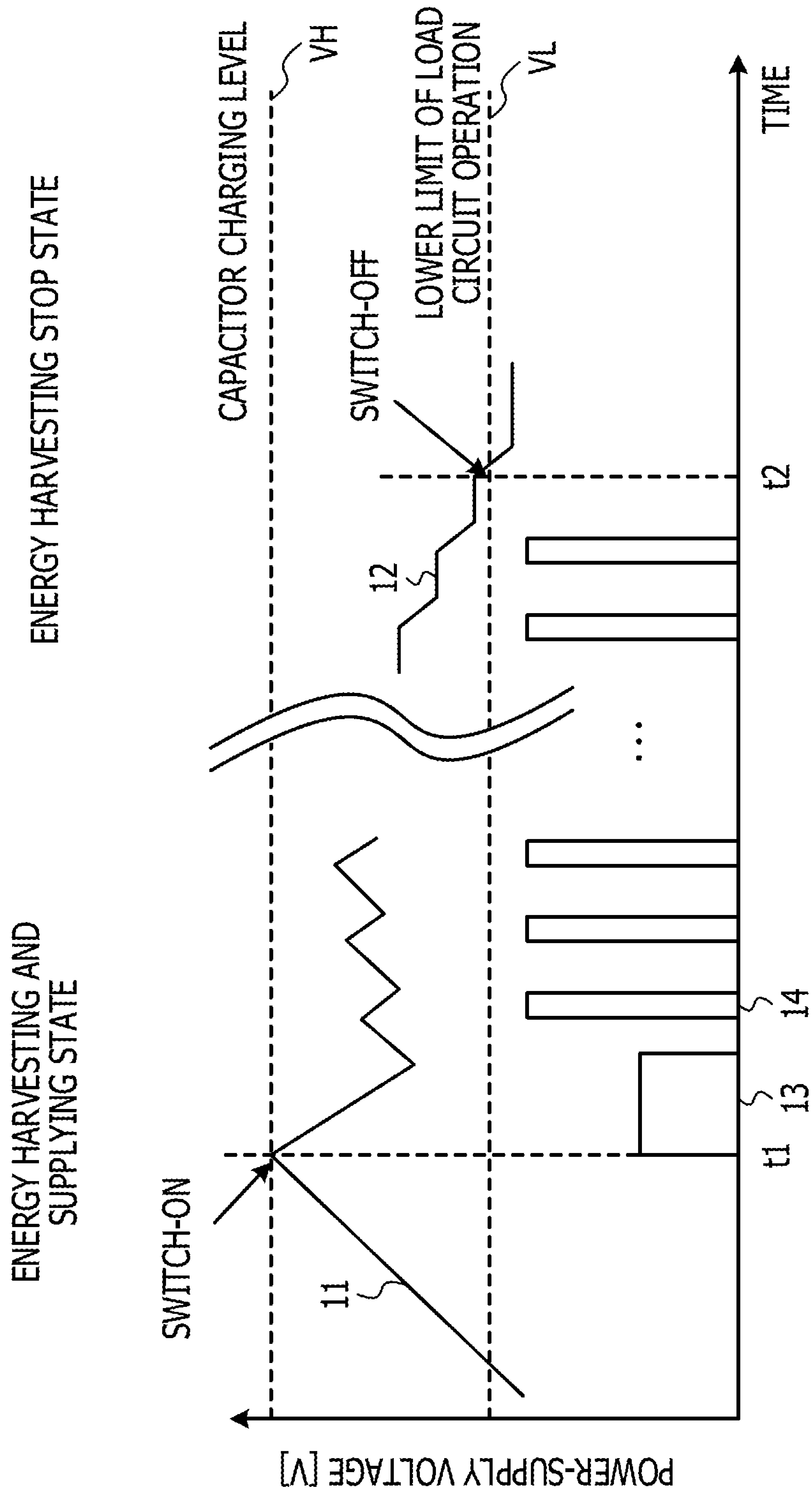
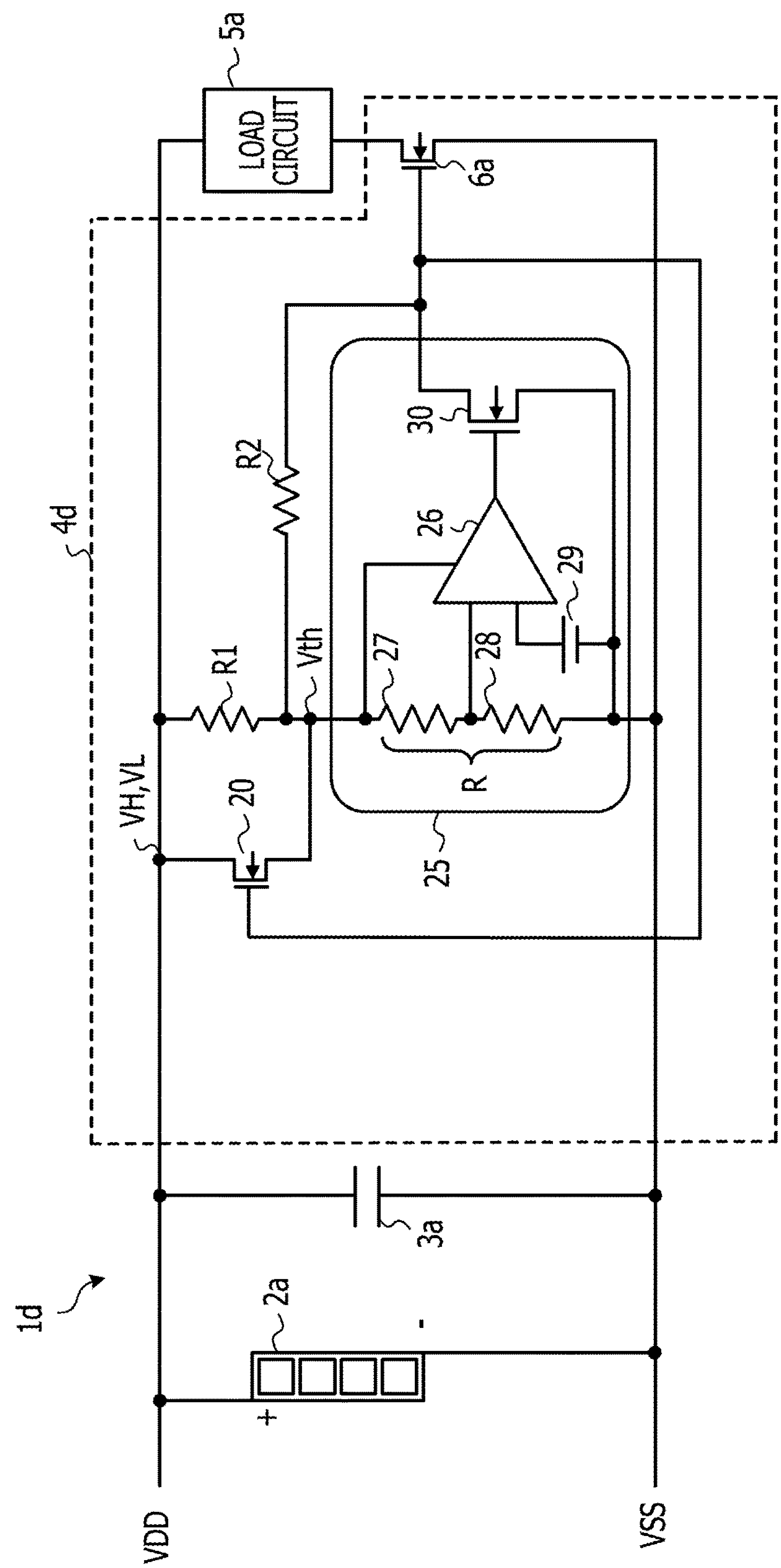

ENERGY HARVESTING AND SUPPLYING STATE
ENERGY HARVESTING STOP STATE
CAPACITOR CHARGING LEVEL
VH
LOWER LIMIT OF LOAD CIRCUIT OPERATION
VL
SWITCH-ON
SWITCH-OFF
11
12
13
14
t1
t2
TIME
POWER-SUPPLY VOLTAGE [V]

FIG. 3



1d
2a
+
-
3a
4d
5a
LOAD CIRCUIT
6a
30
R2
26
29
R1
Vth
27
28
VH,VL
20
R
25
VDD
VSS

FIG. 4

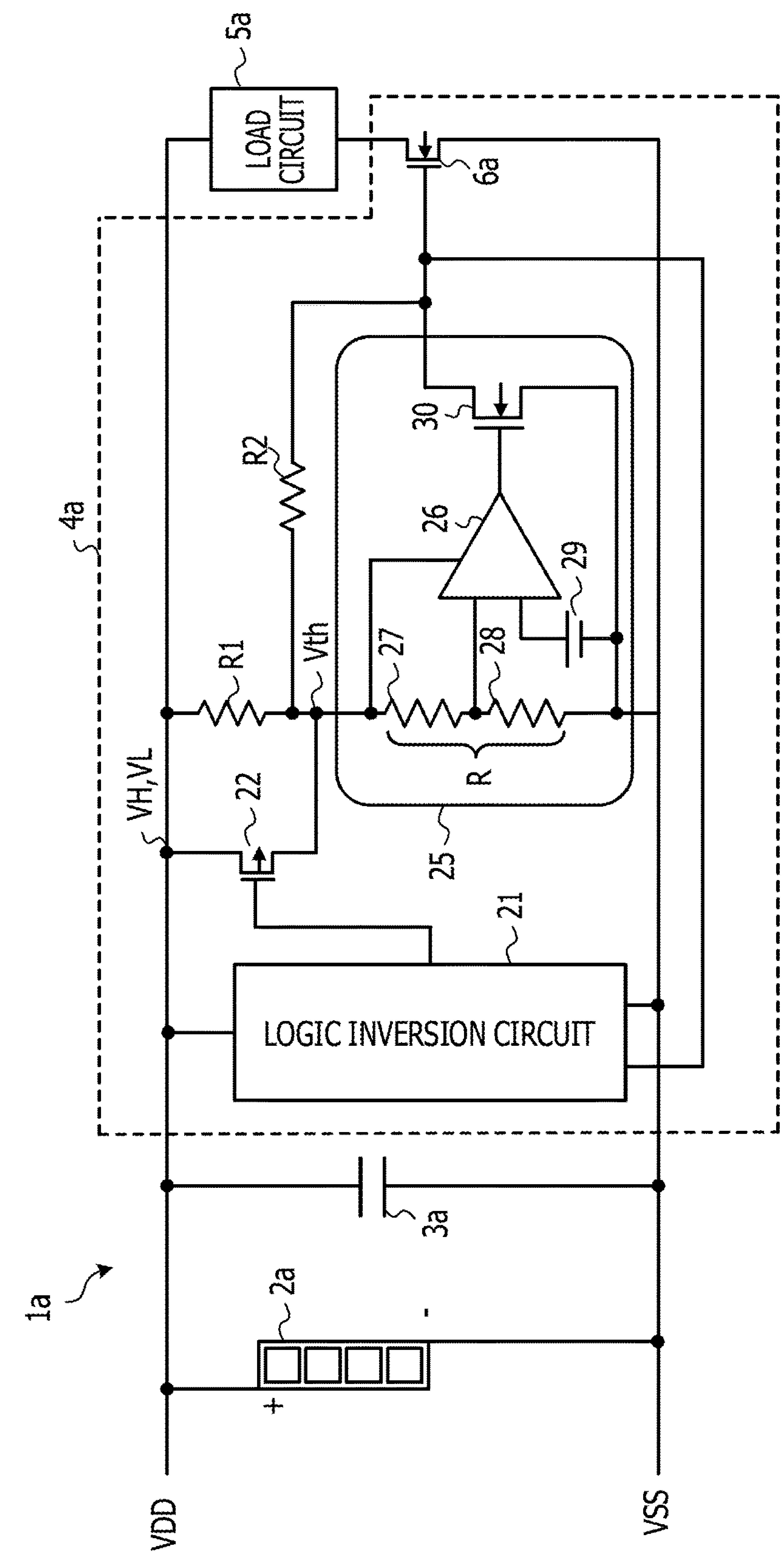
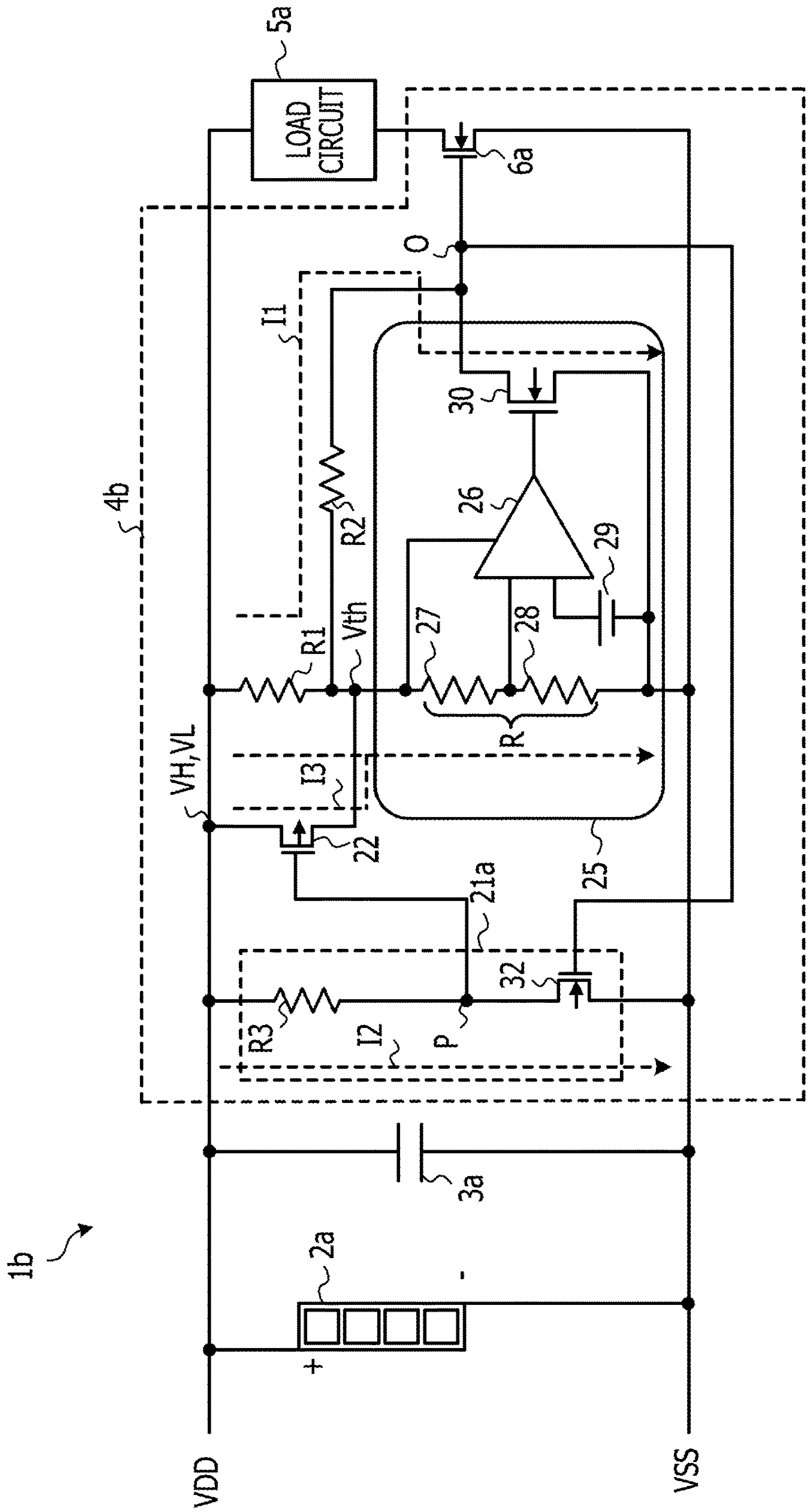

5a
LOAD CIRCUIT
6a
4a
R2
30
26
29
27
28
R1
Vth
VH,VL
22
R
25
21
LOGIC INVERSION CIRCUIT
3a
2a
1a
+
-
VDD
VSS

FIG. 5



1b
2a
3a
4b
5a
6a
LOAD CIRCUIT
VDD
VSS
VH,VL
R1
R2
R3
Vth
R
I1
I2
I3
O
P
21a
22
25
26
27
28
29
30
32

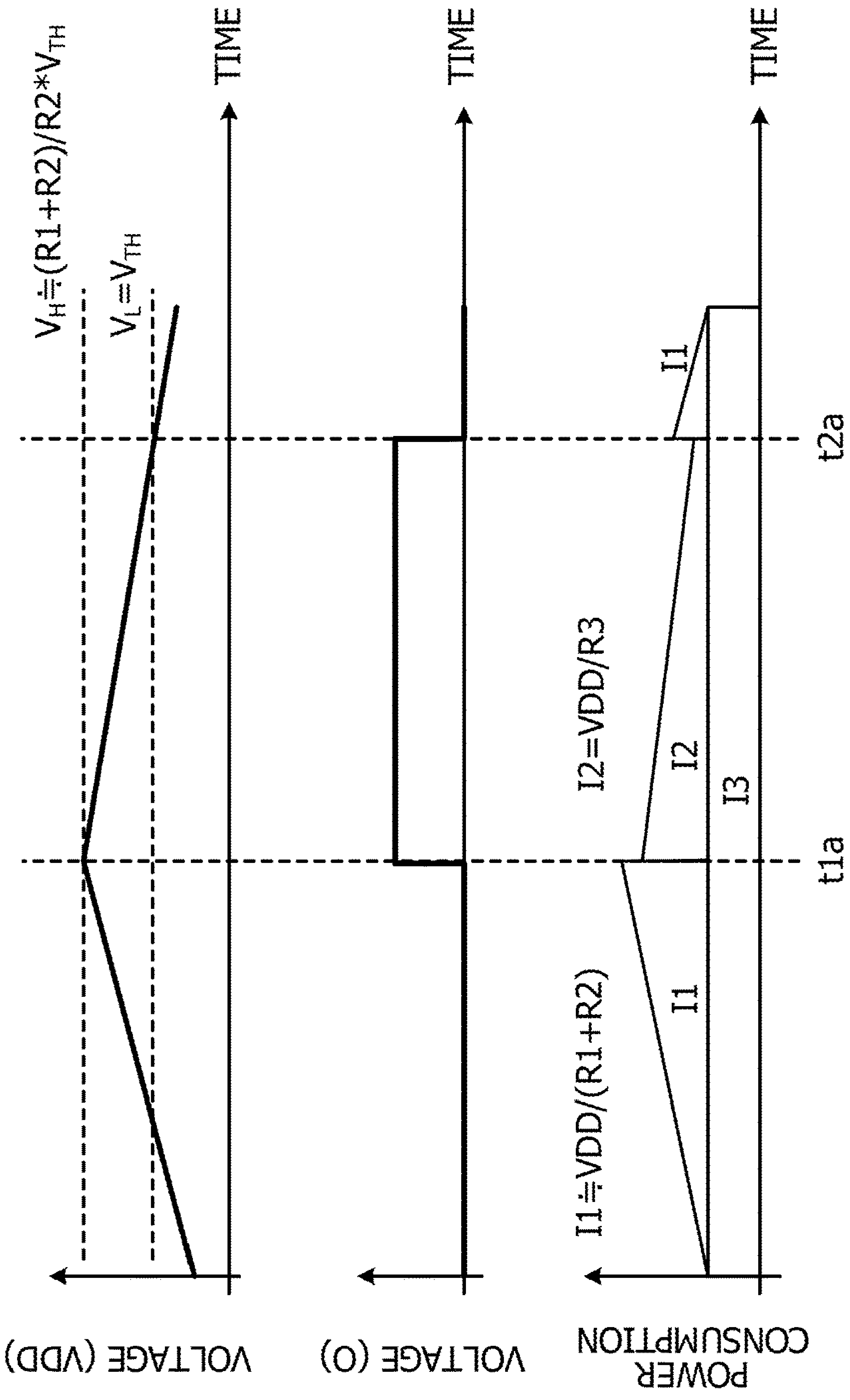


FIG. 6A

FIG. 6B

FIG. 6C

FIG. 7

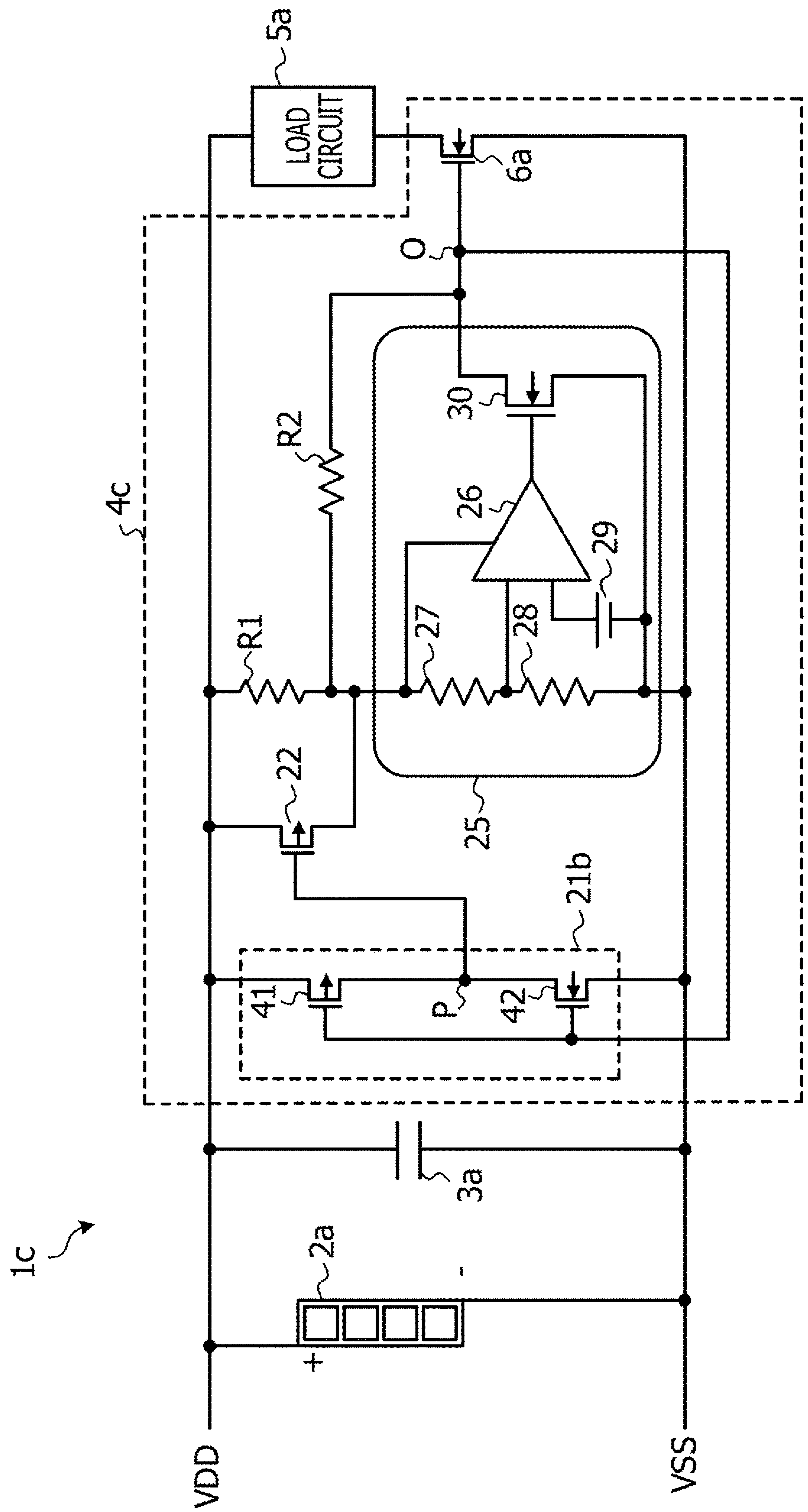
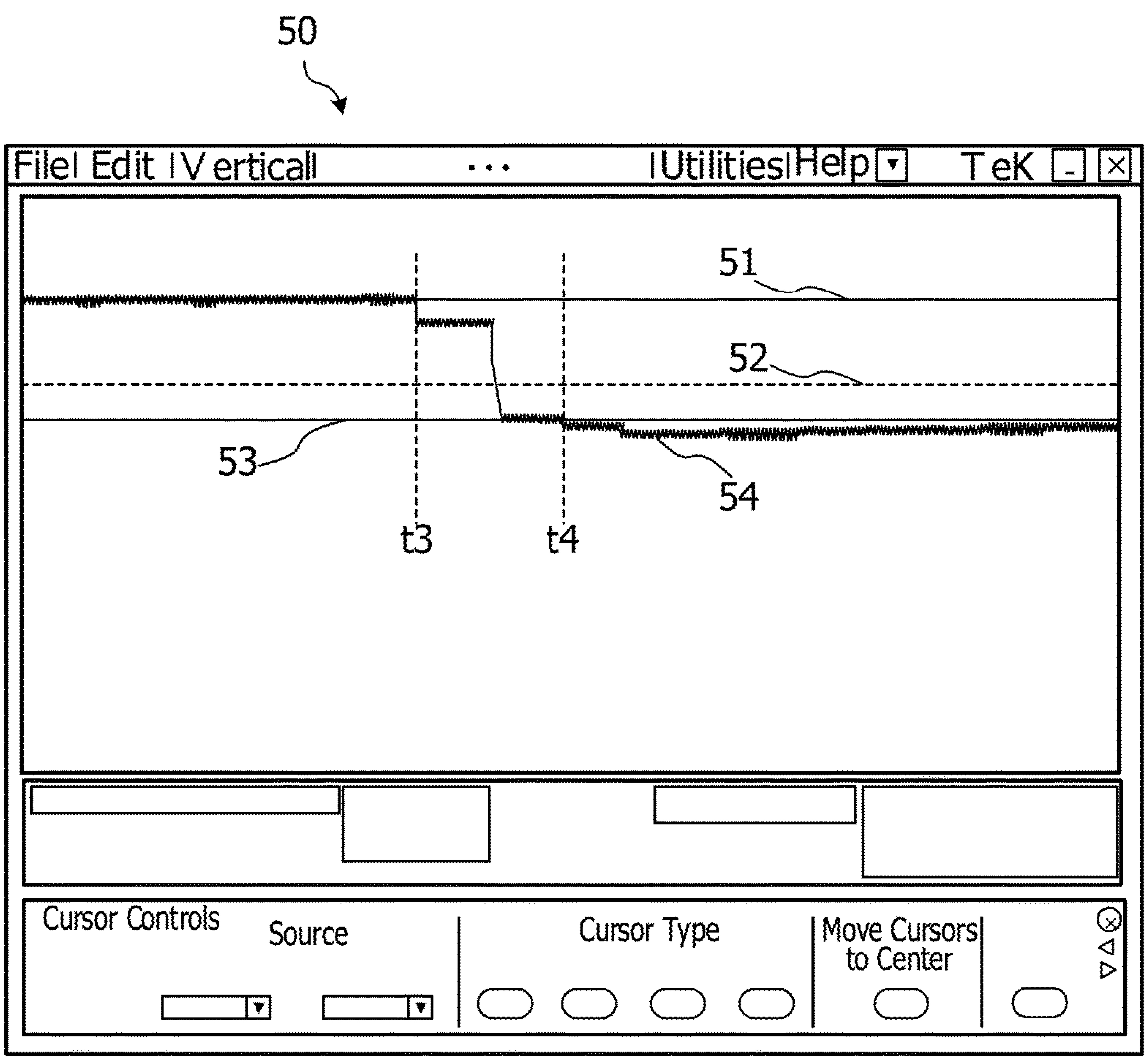

5a
LOAD CIRCUIT
6a
O
4c
R2
30
26
29
R1
27
28
22
25
21b
41
P
42
3a
1c
2a
+
-
VDD
VSS

FIG. 8


50
File Edit Vertical
...
Utilities Help
TeK
51
52
53
54
t3
t4
Cursor Controls
Source
Cursor Type
Move Cursors to Center

POWER SUPPLY CONTROLLER AND ENERGY HARVESTING APPARATUS

CROSS-REFERENCE TO RELATED APPLICATION

This application is based upon and claims the benefit of priority of the prior Japanese Patent Application No. 2016-227303, filed on Nov. 22, 2016, the entire contents of which are incorporated herein by reference.

FIELD

The embodiments discussed herein are related to a power supply controller and an energy harvesting apparatus.

BACKGROUND

Along with miniaturization of wireless communication devices and capacity enlargement of wireless communication, internet of things (IoT) devices that each incorporate a sensor device to sense various pieces of information in a living environment and that each transmit the sensed pieces of information to a server become popular.

Usually, the IoT devices each implement therein a sensing device and a load circuit such as an integrated circuit (IC) for processing sensed data. Since power supply is desired for driving the load circuit, a battery is mounted in each of the IoT devices. In order to cause each of the IoT devices to be driven for a long period of time, it is desirable to replace a battery. However, in a case where the number of installed IoT devices is large, a considerable cost is produced for replacing batteries.

As a power source that drives the load circuit and that is different from the battery, there is an energy harvesting element such as photovoltaic power generation, which converts environmental energy into electric energy. As low power consumption of the load circuit is accelerated, an increase in power generation performance of the energy harvesting element enables an IoT device to be realized, which uses, as a power source for the load circuit, the energy harvesting element in place of the battery.

On the other hand, since being greatly influenced by a change in an environment, a power generation amount based on the energy harvesting element becomes unstable. A power supply controller for stably supplying power to the load circuit is desired for reliability improvement of the IoT device. In, for example, Japanese Laid-open Patent Publication No. 2016-146156, there is disclosed a technique in which two reset ICs to operate based on different threshold voltages are provided and in which hysteresis operations are performed at a time of an increase in a power-supply voltage and at a time of a decrease therein, thereby stabilizing power supply to the load circuit. In addition, in "product FAQs", FAQ:VD_0005_1.0, [searched on May 19, 2016], the Internet <URL:http://datasheet.sii-ic.com/pub/ic/speedfaq/jpn/power/vd/FVD5.PDF>, there is disclosed a technique for adding a resistance circuit to the outside of a reset IC, thereby widening a hysteresis. By realizing an adequate hysteresis operation, the power supply controller avoids troublesome occurrences of a connection and disconnection to and from the load circuit for a fluctuation of a value of a voltage supplied by the energy harvesting element. As a result, it is possible for the power supply controller to stabilize power supply from the energy harvesting element to the load circuit. A technique of the related art is disclosed in Japanese Laid-open Patent Publication No. 08-018010.

SUMMARY

According to an aspect of the invention, a power supply controller that controls a connection between a power source and a capacitor coupled in parallel between a first node and a second node and a load circuit that operates with electric charge supplied by the capacitor, the power supply controller includes a first controller configured to output a first control signal in accordance with an electric potential difference between the first node and the second node, a first switch configured to couple or uncouple the capacitor to or from the load circuit in response to the first control signal, a first resistor coupled between the first node and the first controller, a second resistor coupled between a node which is located between the first resistor and the first controller and a third node for outputting the first control signal, and a second switch coupled in parallel to the first resistor and configured to be put into an on-state or an off-state in response to the first control signal.

The object and advantages of the invention will be realized and attained by means of the elements and combinations particularly pointed out in the claims.

It is to be understood that both the foregoing general description and the following detailed description are exemplary and explanatory and are not restrictive of the invention, as claimed.

BRIEF DESCRIPTION OF DRAWINGS

FIG. **1** is a functional block diagram illustrating an example of an energy harvesting apparatus in a first embodiment;

FIG. **2** is a timing chart of the energy harvesting apparatus;

FIG. **3** is a circuit diagram illustrating an example of the energy harvesting apparatus in a second embodiment;

FIG. **4** is a circuit diagram illustrating an example of the energy harvesting apparatus in a third embodiment;

FIG. **5** is a circuit diagram illustrating an example of the energy harvesting apparatus in a fourth embodiment;

FIGS. **6**A to **6**C are timing charts for explaining an operation of the energy harvesting apparatus;

FIG. **7** is a circuit diagram illustrating an example of the energy harvesting apparatus in a fifth embodiment; and

FIG. **8** is a measurement result of a power-supply voltage value of the energy harvesting apparatus of the present embodiments.

DESCRIPTION OF EMBODIMENTS

Since, in the technique of Japanese Laid-open Patent Publication No. 2016-146156, it is desirable to mount two reset ICs, a mounting area of a circuit becomes large. In addition, in "product FAQs", FAQ:VD_0005_1.0, [searched on May 19, 2016], the Internet <URL:http://datasheet.sii-ic.com/pub/ic/speedfaq/jpn/power/vd/FVD5.PDF>, a current continues flowing through the outside resistance circuit at a time of an increase in a power-supply voltage. Therefore, power consumption becomes large.

An object of the disclosed technology is to realize power supply control with a small mounting area and small power consumption.

Hereinafter, embodiments of the present technology will be specifically described.

First Embodiment

FIG. **1** is a functional block diagram illustrating an example of an energy harvesting apparatus in a first embodiment. In FIG. **1**, an energy harvesting apparatus **1** includes an energy harvesting element **2**, a capacitor **3**, a power supply controller **4**, and a load circuit **5**. A terminal VDD and a terminal VSS are common terminals for electrically connecting the energy harvesting element **2** with other circuits.

The energy harvesting element **2** is an element that converts, into electric energy, environmental energy received from the outside of the element, thereby generating electric power. The energy harvesting element **2** functions as a current source. Examples of the energy harvesting element include a photovoltaic power generation element, a piezo element, a piezoelectric element, and so forth. The capacitor **3** is connected in parallel to the energy harvesting element **2**. Since electric charge power-generated and supplied to the capacitor **3** by the harvesting element **2** is influenced by an external environment, supply power is unstable against a lapse of time. The capacitor **3** accumulates electric charge supplied by the energy harvesting element **2** and functions as a secondary battery for stabilizing electric power supplied to circuits. The electric charge accumulated by the capacitor **3** is able to be monitored as a voltage.

In accordance with a monitoring result of a voltage equivalent to the electric charge accumulated by the capacitor **3**, the power supply controller **4** controls power supply to the load circuit **5**.

The load circuit **5** is an IC driven by the energy harvesting element **2**. The load circuit **5** is a wireless IC or a sensor device, for example. The load circuit **5** is a device that consumes low power and that is operable with electric power power-generated and supplied by the energy harvesting element **2**.

FIG. **2** is a timing chart of the energy harvesting apparatus. In FIG. **2**, regarding the energy harvesting apparatus **1**, a waveform **11** and a waveform **12** each indicate a temporal change in a power-supply voltage value between power-supply terminals to which the capacitor **3** is connected. A waveform **13** and a waveform **14** each indicate power consumption in the load circuit **5**. In each of the waveform **13** and the waveform **14**, a horizontal length of a rectangle shape indicates a power consumption time period based on the load circuit **5**, and a longitudinal length of the rectangle shape indicates a magnitude of power consumption based on the load circuit **5**. The waveform **13** indicates power consumption in setup processing performed by the load circuit **5** and subsequent to power activation, for example. In addition, the waveform **14** indicates power consumption based on event processing operations such as sensing processing and data transmission processing after completion of setup, which intermittently occur. In a case where power consumption in the load circuit **5** occurs, the electric charge accumulated by the capacitor **3** is discharged into the load circuit **5**. The power-supply voltage value is decreased in accordance with a discharge amount of electric charge of the capacitor **3**.

A threshold value VH and a threshold value VL are threshold values set in the power supply controller **4**. The power supply controller **4** monitors the power supply terminals of the capacitor **3** and electrically connects the capacitor **3** and the load circuit **5** to each other in a case where the power-supply voltage value becomes greater than or equal to the threshold value VH. In addition, in a case where the voltage value between the power supply terminals of the capacitor **3** becomes less than or equal to the threshold value VL after starting driving the load circuit **5**, the power supply controller **4** electrically disconnects the capacitor **3** and the load circuit **5** from each other.

In a case where the energy harvesting element **2** starts electric power generation, the power-supply voltage value of the capacitor **3** starts increasing as illustrated by the waveform **11**. In a case where, at a time t**1**, the power-supply voltage value becomes greater than or equal to the threshold value VH, power consumption based on the setup processing of the load circuit **5** occurs as illustrated by the waveform **13**. While electric charge supply from the capacitor **3** to the load circuit **5** causes the waveform **11** to fall after the time t**1**, electric charge power-generated by the energy harvesting element **2** is supplied to the capacitor **3**. After that, the waveform **11** repeats falling caused by an intermittent operation of the load circuit **5** and rising caused by electric charge supply based on the energy harvesting element **2**, as illustrated by the waveform **14**.

In a case where a change in the external environment causes the power generation of the energy harvesting element **2** to stop, supply of electric charge to the capacitor **3** stops. Therefore, the power-supply voltage value of the capacitor **3** decreases in association with the operation of the load circuit **5**, as illustrated by the waveform **12**. In a case where the power-supply voltage value illustrated by the waveform **12** becomes less than or equal to the threshold value VL at a time t**2**, the power supply controller **4** stops supplying electric charge from the capacitor **3** to the load circuit **5**. Therefore, the load circuit **5** stops an operation. The external environment changes after the time t**2**, and the energy harvesting element **2** resumes the electric power generation. Accordingly, the energy harvesting apparatus **1** repeats the above-mentioned operation.

In order to cause the energy harvesting apparatus **1** to perform a stable operation, it is important to obtain a balance between a charge amount accumulated in the capacitor **3** by the energy harvesting and electric power consumed by the load circuit **5**. If consumption conditions such as a power consumption time period and a charge amount in the load circuit **5** are understood beforehand, it is possible to optimize, in conformity with the consumption conditions, the threshold values VH and VL, the power generation amount of the energy harvesting element **2**, and a capacity of the capacitor **3**.

As described above, regardless of a change in the power generation amount of the energy harvesting element **2**, associated with a change in the external environment, the power supply controller **4** is able to control so as to supply stable electric power to the load circuit **5**.

Second Embodiment

FIG. **3** is a circuit diagram illustrating an example of the energy harvesting apparatus in a second embodiment. In FIG. **3**, an energy harvesting apparatus **1*d*** includes a photovoltaic power generation element **2*a***, a capacitor **3*a***, a power supply controller **4*d***, and a load circuit **5*a***.

The photovoltaic power generation element **2*a*** is one of energy harvesting elements and converts sunlight energy into electric energy. The capacitor **3*a*** accumulates electric charge supplied by the photovoltaic power generation element **2*a*** and functions as a secondary battery for stabilizing electric charge supplied to the load circuit.

In accordance with a monitoring result of a voltage equivalent to the electric charge accumulated by the capacitor **3***a*, the power supply controller **4***d* controls power supply to circuits. In accordance with the monitoring result, the power supply controller **4***d* controls an on-state and an off-state of a switch **6***a*.

The load circuit **5***a* is a circuit to which the photovoltaic power generation element **2***a* supplies electric power. The load circuit **5** is a wireless IC or a sensor device, for example. The load circuit **5***a* is a device that consumes low power and that is operable with electric power power-generated and supplied by the photovoltaic power generation element **2***a*.

The power supply controller **4***d* includes a switch **20**, a resistor R**1**, a resistor R**2**, a voltage detection circuit **25**, and the switch **6***a*.

The switch **20** is a switch element for connecting or disconnecting the terminal VDD and a terminal Vth serving as a power-supply input of the voltage detection circuit **25** to or from each other, in response to a logic level of a control signal input to the switch **6***a*. In FIG. **3**, the switch **20** is an NMOS transistor, and a conduction state is established between a source and a drain in a case where a control signal having a high-logic level is input to a gate terminal. The resistors R**1** and R**2** are resistance elements having resistance values R**1** and R**2**, respectively. A voltage value of the terminal Vth is determined depending on the resistance values R**1** and R**2**.

The voltage detection circuit **25** is connected between the terminal Vth and the terminal VSS. The voltage detection circuit **25** is a controller that determines, in accordance with the voltage value of the terminal Vth, the logic level of the control signal to be output. The voltage detection circuit **25** includes a resistor **27**, a resistor **28**, a comparator **26**, a voltage source **29**, and a switch **30**. The resistor **27** and the resistor **28** are connected in series between the terminal Vth and the terminal VSS. A total resistance value at a time of series-connecting the resistor **27** and the resistor **28** is "R". In accordance with a result of a comparison between a voltage-dividing value based on the resistor **27** and the resistor **28** and a voltage value of the voltage source **29**, the comparator **26** determines the logic level of the output signal. The voltage source **29** generates a reference potential for determining a logic level of a signal to be input to the comparator **26**. The switch **30** is an NMOS transistor, and an on-state is established between a source and a drain in a case where the comparator **26** inputs an output signal having a high-logic level to a gate terminal. In a case where the switch **30** is put into an on-state, the logic level of the control signal output by the voltage detection circuit **25** is put into "low".

The switch **6***a* is a switch element for putting an electric connection relationship between the photovoltaic power generation element **2***a* and the load circuit **5***a* into "connected" or "disconnected". In response to the logic level of the control signal output by the voltage detection circuit **25**, the switch **6***a* switches between "connected" and "disconnected". In FIG. **3**, the switch **6***a* is an NMOS transistor, for example, and a conduction state is established between a source and a drain in a case where the control signal having a high-logic level is input to a gate terminal.

In a case where the switch **6***a* is in an off-state and the voltage value of the terminal VDD is increasing, the switch **30** is put into an on-state. Therefore, current paths from the terminal VDD to the terminal VSS are a path in which a current flows through the resistors R**1** and R**2** and a path in which a current flows through the resistor R**1** and the resistors **27** and **28**. In a case where the resistance value R is considerably larger than the resistance values R**1** and R**2**, the path in which a current flows through the resistors R**1** and R**2** predominates as the amount of a current that flows from the terminal VDD to the terminal VSS. Therefore, by using the voltage value Vth between the resistor R**1** and the resistor R**2**, the threshold voltage VH satisfies $VH=Vth\times\{R1\times(R2+R)+R2\times R\}/\{R2\times R\}\approx Vth\times(R1+R2)/R2$.

In a case where the voltage value of the terminal VDD is decreasing after the switch **6***a* is put into an on-state, the switch **30** is put into an off-state. Therefore, a current path from the terminal VDD to the terminal VSS is a path in which a current flows through the resistor R**1** and the resistors **27** and **28**. In a case where the resistance value R is considerably larger than the resistance value R**1**, the threshold voltage VL satisfies $VL=Vth\times(R+R1)/R\approx Vth$, by using the voltage value Vth.

At a time of an increase in the voltage of the terminal VDD, the resistance values R**1** and R**2** are considerably smaller than the resistance value R. Therefore, power consumption at a time of an increase in the voltage increases. In a case where, in order to decrease power consumption at a time of an increase in the voltage, the resistance values R**1** and R**2** are decreased, the influence of the resistance values R**1** and R**2** on the threshold values VH and VL becomes unignorable, and it becomes difficult to ensure an adequate hysteresis operation for stabilizing a circuit operation associated with a voltage fluctuation of the terminal VDD. In addition, the amount of a current supplied to the comparator **26** is influenced by the resistor R**1**. Therefore, in a case of increasing the resistance value R**1**, a switching speed of the comparator **26** is reduced, and the voltage detection operation of the voltage detection circuit **25** becomes unstable.

Therefore, the energy harvesting apparatus **1***d* in FIG. **3** includes the switch **20** so as to stabilize the operation of the voltage detection circuit **25** even in a case where the resistance values of the resistors R**1** and R**2** are large. Hereinafter, an operation of the energy harvesting apparatus **1***d* at a time of a decrease in the power-supply voltage VDD will be described.

In a case where the power-supply voltage VDD increases and becomes greater than or equal to the threshold value VH, the switch **30** in the voltage detection circuit **25** is put into an off-state. In a case where the switch **30** is put into an off-state, the gate input voltage of the switch **6***a* becomes "high". Therefore, the gate input voltage input to the switch **20** becomes "high". The switch **20** is put into an on-state or an off-state, based on the same logic as that of the switch **6***a*. Therefore, in a case where the voltage level input to the switch **20** becomes "high", the switch **20** is put into an off-state.

In a case where the switch **20** is put into an on-state, a resistance value from the terminal VDD to the terminal Vth is a resistance value based on a parallel connection between the on-resistance of the switch **20** and the resistor R**1**. Since the on-resistance value of the switch **20** is sufficiently smaller than the resistor R**1**, the on-resistance value of the switch **20** predominates as the resistance value from the terminal VDD to the terminal Vth. Therefore, the switch **20** is put into an on-state at a time of a decrease in the power-supply voltage, thereby reducing the influence of the resistor R**1** on the threshold voltage VL. Accordingly, it is possible to realize an adequate hysteresis operation, and it is possible to stabilize the operation of the voltage detection circuit **25**.

Third Embodiment

FIG. **4** is a circuit diagram illustrating an example of the energy harvesting apparatus in a third embodiment. In FIG.

4, an energy harvesting apparatus **1***a* includes the photovoltaic power generation element **2***a*, the capacitor **3***a*, a power supply controller **4***a*, and the load circuit **5***a*. Here, the same reference symbol is assigned to the same configuration item as that of another energy harvesting apparatus, and a description thereof will be omitted.

The power supply controller **4***a* includes a logic inversion circuit **21**, a switch **22**, the resistor R**1**, the resistor R**2**, the voltage detection circuit **25**, and the switch **6***a*.

In a case where the switch **20** connected in parallel to the resistor R**1** is configured by an NMOS transistor as illustrated in FIG. **3**, if the logic level of the gate input voltage is "low", a source terminal is connected to the terminal Vth, and accordingly, there is a possibility that an operation is not guaranteed. In addition, in a case where the logic level of the gate input voltage is "high", if an electric potential difference between a gate and a source is small, the on-resistance value of the switch **20** is likely to increase.

Therefore, in order to further stabilize the operation of the voltage detection circuit **25** even in a case where the resistance values of the resistors R**1** and R**2** are large, the energy harvesting apparatus **1***a* in FIG. **4** includes the logic inversion circuit **21** and the switch **22**. The logic inversion circuit **21** is a controller that inverts a logic level of an input signal and outputs the input signal. Hereinafter, an operation of the energy harvesting apparatus **1***a* at a time of a decrease in the power-supply voltage VDD will be described.

In a case where the voltage value of the capacitor **3***a* increases and becomes greater than or equal to the threshold value VH, the switch **30** in the voltage detection circuit **25** is put into an off-state. In a case where the switch **30** is put into an off-state, the gate input voltage of the switch **6***a* becomes "high". Therefore, the input voltage of the logic inversion circuit **21** becomes "high". The logic inversion circuit **21** inverts the logic of an input signal and outputs the input signal. Therefore, in a case where the input voltage is "high", a voltage level output to the switch **22** becomes "low". The switch **22** is put into an on-state or an off-state, based on a logic opposite to that of the switch **6***a*. Therefore, in a case where the voltage level input to the switch **22** becomes "low", the switch **22** is put into an on-state.

In a case where the switch **22** is put into an on-state, a resistance value from the terminal VDD to the terminal Vth is a resistance value based on a parallel connection between the on-resistance of the switch **22** and the resistor R**1**. Since the on-resistance value of the switch **22** is sufficiently smaller than the resistor R**1**, the on-resistance value of the switch **22** predominates as the resistance value from the terminal VDD to the terminal Vth. Therefore, the switch **22** is put into an on-state at a time of a decrease in the power-supply voltage, thereby considerably reducing the influence of the resistor R**1** on the threshold voltage VL. Accordingly, it is possible to realize an adequate hysteresis operation, and it is possible to stabilize the operation of the voltage detection circuit **25**. In addition, the switch **22** is configured by a PMOS transistor, and accordingly, an electric potential difference between a gate and a source at a time of an off-state is considerably increased, thereby stabilizing an off-operation. In attrition, it is possible to considerably decrease the on-resistance value at a time of an on-state, compared with the resistor R**1**.

Fourth Embodiment

FIG. **5** is a circuit diagram illustrating an example of the energy harvesting apparatus in a fourth embodiment. In FIG. **4**, an energy harvesting apparatus **1***b* includes the photovoltaic power generation element **2***a*, the capacitor **3***a*, a power supply controller **4***b*, and the load circuit **5***a*. Compared with the energy harvesting apparatus **1***a* in FIG. **4**, the energy harvesting apparatus **1***b* in FIG. **5** includes a logic inversion circuit **21***a* serving as a specific example of the logic inversion circuit **21**. A current I**1** is a current that passes through the resistors R**1** and R**2** and the switch **30** and that flows from the terminal VDD to the terminal VSS. A current I**2** is a current that passes through a resistor R**3** and a switch **32** and that flows from the terminal VDD to the terminal VSS. A current I**3** is a current that passes through a parallel circuit based on the resistor R**1** and the switch **22**, the resistor **27**, and the resistor **28** and that flows from the terminal VDD to the terminal VSS.

The power supply controller **4***b* includes the logic inversion circuit **21***a*, the switch **22**, the resistor R**1**, the resistor R**2**, the voltage detection circuit **25**, and the switch **6***a*. The logic inversion circuit **21***a* includes the resistor R**3** and the switch **32**.

The resistor R**3** is a resistance element having a resistance value R**3**. The resistance value of the resistor R**3** may be set to a value nearly several times as large as the resistor R**2**. By increasing the resistance value of the resistor R**3**, it is possible to restrict the amount of a current that flows from the terminal VDD to the terminal VSS in a case where the switch **32** is in an on-state.

In a case where a logic level of an input signal is "high", the switch **32** is put into an on-state. The switch **32** is an NMOS transistor, for example. In a case where a logic level of an input signal of the logic inversion circuit **21***a* becomes "high", the switch **32** is put into an on-state, and a voltage value of a contact P drops. The contact P is an output node of the logic inversion circuit **21***a*. A voltage value of an output signal of the logic inversion circuit **21***a* is equal to the voltage value of the contact P. Therefore, in a case where the voltage value of the contact P drops, a logic level of the output signal of the logic inversion circuit **21***a* becomes "low". Therefore, in a case where the logic level of the input signal of the logic inversion circuit **21***a* is "high", the logic level of the output signal of the logic inversion circuit **21***a* becomes "low".

In a case where the switch **32** is in an on-state in the logic inversion circuit **21***a*, the amount of a current that flows from the terminal VDD to the terminal VSS depends on the resistance value of the resistor R**3**. In order to suppress power consumption of the energy harvesting apparatus **1***b* in a case where the switch **32** is in an on-state, it is desirable to considerably increase the resistance value of the resistor R**3**. In a case where an off-resistance value of the switch **32** is, for example, several Giga Ω in an off-state of the switch **32**, if the resistance value of the resistor R**3** is set to about 100 M Ω, it is possible to set the voltage value of the contact P so that a logic level for putting the switch **22** into an off-state becomes "high". In addition, in a case where the resistance value of the resistor R**3** is increased, the amount of a current supplied to the switch **22** is decreased, and accordingly, a switching time of the switch **22** is lengthened. An acceptable value of the switching time depends on a starting time of activation of the load circuit **5***a*. In a case where it is assumed that a gate capacitance value of the switch **22** is "C**1**", a time constant T in switching of the switch **22** satisfies $T=1/(2\pi\times R3\times C1)$. As described above, by taking into consideration an on-off action of the switch **22**, it is possible to optimize the resistance value of the resistor R**3** while considering power consumption in an on-state of the switch **32**.

FIGS. 6A to 6C are timing charts for explaining an operation of the energy harvesting apparatus. FIG. 6A illustrates a change in voltage of the terminal VDD in the energy harvesting apparatus **1***b*, based on the terminal VSS. FIG. 6B illustrates a change in voltage of a contact O in the energy harvesting apparatus **1***b*, based on the terminal VSS. FIG. 6C illustrates a change in power consumption of the energy harvesting apparatus **1***b*, in other words, changes in the currents I**1**, I**2**, and I**3**, in the energy harvesting apparatus **1***b*.

The photovoltaic power generation element **2***a* performs electric power generation between a time **0** and a time t**1***a*, thereby accumulating electric charge in the capacitor **3***a*, and the voltage value of the terminal VDD increases as illustrated in FIG. **6**A. In a case where the voltage value of the terminal VDD becomes greater than or equal to the threshold value VH at the time t**1***a*, a logic level of the contact O changes from "low" to "high", as illustrated in FIG. **6**B. Since the switch **30** is in an on-state between the time **0** and the time t**1***a*, the currents I**1** and I**3** flow through the energy harvesting apparatus **1***b*. The current I**1** increases with an increase in the voltage value of the terminal VDD. On the other hand, the resistance value R of the resistor **27** and resistor **28** located in a current path of the current I**3** is considerably larger than the resistance values of the resistors R**1** and the resistor R**2**. Therefore, the current value of the current I**3** is considerably smaller than that of the current I**1**. Therefore, compared with the current I**1**, the current I**3** is approximately fixed, as illustrated in FIG. **6**C.

In a case where the logic level of the contact O reaches "high" at the time t**1***a*, the switch **6***a* is put into an on-state, and the capacitor **3***a* starts supplying electric charge to the load circuit **5***a*. At a time of supplying electric charge to the load circuit **5***a*, the switch **30** is put into an off-state, and the switch **32** is put into an on-state. Therefore, as illustrated in FIG. **6**C, the amount of current of the current I**2** predominates after the time t**1***a*. Discharge of the capacitor **3***a* causes the voltage value of the terminal VDD to gradually decrease as illustrated in FIG. **6**A, and the current I**2** gradually decreases as illustrated in FIG. **6**C.

In a case where, as illustrated in FIG. **6**A, the voltage value of the terminal VDD becomes less than or equal to the threshold value VL at a time t**2***a*, the switch **30** is put into an on-state, and the logic level of the voltage value of the contact O is switched from "high" to "low", as illustrated in FIG. **6**B. The logic level of the voltage value of the contact O is put into "low", thereby putting the switch **32** into an off-state. Therefore, a path of the current I**2** is disconnected as illustrated in FIG. **6**C, and the current I**1** predominates. Even in a case where the switch **6***a* is put into an off-state and electric charge supply to the load circuit **5***a* is stopped, the current I**1** continues flowing. Therefore, the voltage value of the terminal VDD gradually decreases as illustrated in FIG. **6**A, and the current value of the current I**1** decreases as illustrated in FIG. **6**C. In a case where a change in an environment causes the photovoltaic power generation element **2***a* to start electric power generation, the voltage of the terminal VDD increases again, and the energy harvesting apparatus **1***b* repeats the above-mentioned operation.

As described above, by providing a sufficient difference between the threshold value VH and the threshold value VL, the energy harvesting apparatus **1***b* is able to realize a stable hysteresis operation against a change in the power-supply voltage of the terminal VDD.

Fifth Embodiment

FIG. **7** is a circuit diagram illustrating an example of the energy harvesting apparatus in a fifth embodiment. In FIG. **7**, an energy harvesting apparatus **1***c* includes the photovoltaic power generation element **2***a*, the capacitor **3***a*, a power supply controller **4***c*, and the load circuit **5***a*. Compared with the energy harvesting apparatus **1***a* in FIG. **4**, the energy harvesting apparatus **1***c* in FIG. **7** includes a logic inversion circuit **21***b* serving as another specific example of the logic inversion circuit **21**.

The power supply controller **4***c* includes the logic inversion circuit **21***b*, the switch **22**, the resistor R**1**, the resistor R**2**, the voltage detection circuit **25**, and the switch **6***a*. The logic inversion circuit **21***b* includes a switch **41** and a switch **42**.

The switch **41** and the switch **42** are each put into an on-state or an off-state in response to the logic level of the electric potential of the contact O. The contact O is the output node of the voltage detection circuit **25**. The switch **41** and the switch **42** are put into an on-state, based on respective logic levels opposite to each other. In the present embodiment, the switch **41** is configured by a PMOS transistor, and the switch **42** is configured by an NMOS transistor, for example.

In a case where the logic level of the electric potential of the contact O is "low", the switch **41** is put into an on-state, and the switch **42** is put into an off-state. In this case, the logic level of the electric potential of the contact P serving as the output of the logic inversion circuit **21***b* is put into "high", and the switch **22** is put into an off-state.

In a case where the logic level of the electric potential of the contact O is "high", the switch **41** is put into an off-state, and the switch **42** is put into an on-state. In this case, the logic level of the electric potential of the contact P serving as the output of the logic inversion circuit **21***b* is put into "low", and the switch **22** is put into an on-state.

In a case where, in the logic inversion circuit **21***b* in the energy harvesting apparatus **1***c*, the logic level of the electric potential of the contact P serving as the output of the logic inversion circuit **21***b* is "low", a value of a current that flows from the terminal VDD to the terminal VSS through the logic inversion circuit **21***b* is determined based on an off-resistance value of the switch **41**. In addition, even in a case where the logic level of the output of the logic inversion circuit **21***b* is any one of "high" and "low", one of the switch **41** and the switch **42** is put into an off-state. Since an off-resistance value of a MOS transistor is several Giga Ω, it is possible to considerably decrease the value of the current that flows from the terminal VDD to the terminal VSS through the logic inversion circuit **21***b*, compared with the logic inversion circuit **21***a*.

FIG. **8** is a measurement result of a power-supply voltage value of the energy harvesting apparatus of the present embodiments. A window **50** is a window of an application that displays a temporal change in a measured power-supply voltage value. A threshold value **51** is an example of the threshold value VH in the present embodiments. A threshold value **53** is an example of the threshold value VL in the present embodiments. In the present embodiment, a value of the threshold value **51** is designed to be 3.1 V, and a value of the threshold value **53** is designed to be 1.9 V. In addition, a threshold value **52** is the threshold value VL in a case where, in a power source control device, there is provided no switch that is able to connect the terminal Vth to the terminal VDD with bypassing the resistor R**1** after starting power supply to the load circuit **5***a*. In the present embodiments, the value of the threshold value **52** is 2.4 V. In the present embodiments, as illustrated in FIG. **8**, it is confirmed that, by providing a switch that is able to connect the terminal Vth to the terminal VDD with bypassing the resistor R**1**, it is possible to decrease the threshold value VL from 2.4 V to 1.9 V.

A waveform **54** indicates a temporal change in the voltage value of the terminal VDD in the energy harvesting apparatus of the present embodiments. At a time t**3** after power supply to the load circuit is started, the voltage value of the terminal VDD starts decreasing for a reason such as stopping of energy harvesting. After that, the voltage value of the terminal VDD gradually decreases and becomes less than or equal to the threshold value **53** at a time t**4**. In a case where the voltage value of the terminal VDD becomes less than or equal to the threshold value VL, power supply to the load circuit is stopped. Therefore, based on the waveform **54**, it is possible to confirm that a decrease in the voltage value of the terminal VDD is stopped.

As described above, based on an actual machine, it is confirmed that the energy harvesting apparatus illustrated in the present embodiments is able to realize power supply control with a small mounting area and small power consumption.

All examples and conditional language recited herein are intended for pedagogical purposes to aid the reader in understanding the invention and the concepts contributed by the inventor to furthering the art, and are to be construed as being without limitation to such specifically recited examples and conditions, nor does the organization of such examples in the specification relate to a showing of the superiority and inferiority of the invention. Although the embodiments of the present invention have been described in detail, it should be understood that the various changes, substitutions, and alterations could be made hereto without departing from the spirit and scope of the invention.

What is claimed is:

1. A power supply controller that controls a connection between a power source and a capacitor coupled in parallel between a first node and a second node, and a load circuit that operates with electric charge supplied by the capacitor, the power supply controller comprising:

- a first controller provided between the first node and the second node and configured to output a first control signal in accordance with an electric potential difference between the first node and the second node;
- a first switch provided between the capacitor and the load circuit, coupled to a third node to which the first control signal is output from the first controller and configured to couple or uncouple the capacitor to or from the load circuit in response to the first control signal;
- a first resistor having one first terminal coupled to the first node and the other first terminal coupled to the first controller;
- a second resistor having one second terminal coupled to the other first terminal and the other second terminal coupled to the third node; and
- a second switch coupled in parallel to the first resistor, having one third terminal coupled to the first node and the other third terminal coupled to the third node and configured to be put into an on-state or an off-state in response to the first control signal.

2. The power supply controller according to claim **1**, further comprising:

- a second controller configured to output a second control signal obtained by inverting a logic of the first control signal, wherein the second switch is put into an on-state or an off-state in response to the second control signal.

3. The power supply controller according to claim **1**, wherein the first controller includes a third resistor and a fourth resistor connected in series between the first resistor and the second node, a comparator configured to output a third control signal in accordance with a result of a comparison between an electric potential at a contact between the third resistor and the fourth resistor and a preset reference potential, and a third switch connected between the third node and the second node and configured to be put into an on-state or an off-state in response to the third control signal.

4. The power supply controller according to claim **2**, wherein the second controller includes a fifth resistor connected between the first node and a fourth node to output the second control signal, and a fourth switch connected between the fourth node and the second node and configured to be put into an on-state or an off-state in response to the first control signal.

5. The power supply controller according to claim **2**, wherein the second controller includes a fourth switch connected between the fourth node and the second node and configured to be put into an on-state or an off-state in response to the first control signal, and a fifth switch connected between the fourth node and the first node and configured to be put into an on-state or an off-state in response to the first control signal, based on a logic opposite to that of the fourth switch.

6. A power supply controller that controls a connection between a power source and a capacitor connected in parallel between a first node and a second node and a load circuit that operates with electric charge supplied by the capacitor, the power supply controller comprising:

- a controller provided between the first node and the second node and configured to output a control signal which is logic inverted in accordance with an electric potential difference between the first node and the second node;
- a first switch provided between the capacitor and the load circuit, coupled to a third node to which the control signal is output from the controller and configured to connect or disconnect the capacitor and the load circuit to or from each other in response to a logic of the control signal;
- a first resistor having one first terminal coupled to the first node and the other first terminal coupled to the controller and configured to restrict current supply from the first node to the controller;
- a second resistor having one second terminal coupled to the other first terminal and the other second terminal coupled to the third node; and
- a second switch connected in parallel to the first resistor, having one third terminal coupled to the first node and the other third terminal coupled to the third node and configured to connect or disconnect the first node and the controller to or from each other in response to the logic of the control signal,
- wherein in a case where the controller outputs the control signal having a logic for putting the first switch into a connection state, the second switch is put into a connection state.

7. An energy harvesting apparatus comprising:

- an energy harvesting device coupled between a first node and a second node; a capacitor coupled in parallel to the energy harvesting device;
- a load circuit configured to operate with electric charge supplied by the capacitor;
- a first controller provided between the first node and the second node and configured to output a first control

signal in accordance with an electric potential difference between the first node and the second node;

a first switch provided between the capacitor and the load circuit, coupled to a third node to which the first control signal is output from the first controller and configured to couple or uncouple the capacitor to or from the load circuit in response to the first control signal;

a first resistor having one first terminal coupled to the first node and the other first terminal coupled to the first controller;

a second resistor having one second terminal coupled to the other first terminal and the other second terminal coupled to the third node; and

a second switch coupled in parallel to the first resistor, having one third terminal coupled to the first node and the other third terminal coupled to the third node and configured to be put into an on-state or an off-state in response to the first control signal.

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